CHAPTER 3
Planting

METHODS

Common to all planting methods are some fundamental constraints. As mentioned earlier, the basic premise is to adjust the ratio of births and deaths of shoots so as to effect net population growth. To achieve this, it is important to ensure the presence of growing rhizome apical meristems in individual planting units (PUs) as these provide a source of new shoots and horizontal growth; one means of colonizing of new areas (as opposed to seeds). Visually inspecting arbitrarily selected planting units for an absolute minimum of one apical shoot per PU is requisite for asexual reproduction; more than one apical is highly recommended. The number of short shoots on a long shoot should be maximized whenever possible so as to derive benefits from the clonal nature of the plants. Fonseca et al. (1987a) used an average of 2.6 short shoots per long shoot (horizontal rhizome with several short shoots) with turtle grass but Tomasko et al. (1991) found higher rates of new short shoot production when the short shoot/long shoot ratio increased (up to a ratio of 4). Davis and Short (1997) use only two *Zostera marina* shoots per planting unit in a modified staple method. It is also recommended that whenever possible, plants should be collected and planted on the same day. Any number of incidents may further shock the plants and inhibit their photosynthetic capacity for prolonged periods after planting. Seagrasses are inherently fragile, having evolved in a fluid medium that provides support for their structure. When out of the water, they are very susceptible to physical damage. To ensure transplanting success, it is critical that seagrasses are kept wet and handled gently. Moreover, seagrasses have very little resistance to desiccation. On a breezy, sunny day, plants left out of the water in the open can experience permanent leaf damange within minutes and protracted loss of photosynthetic efficiency within 1-2 hours (author's unpubl. data). Plants must be kept in ambient temperature and salinity water at all times! They may be covered with seawater-soaked cloth for short periods if transportation is necessary. Stacking of the plants on one another should be minimized. Although they appear and even feel robust, they are easily bruised and broken.

Numerous methods have been shown to successfully establish seagrass; however, familiarity with handling and planting methods as well as the ability to work in or under the water are requisite. The familiarity of an individual with these plant communities is inversely proportional to the difficulty encountered in executing a planting. Candidates for planting projects should be able to identify the species involved and, if needed, have the ability to snorkel or SCUBA dive. Planting inexperience is one of the most common causes of problems (and added cost) in a project failure.

Planting strategies can be divided into SCUBA and non-SCUBA assisted operations. In either case, once the required area for planting is selected, the planting area should be clearly marked off so its boundaries are visible from the surface (e.g., poles, buoys). Experienced boat operators and SCUBA divers may be required. The decision to utilize SCUBA does not necessarily mean that depths are over one's head. Where the water is deep enough to prevent a snorkeling diver from reaching the bottom without breath-holding, a person walking and either handing planting units (PUs) to the diver or pre-placing them for installation can greatly reduce physical exertion. Various combinations of planting and providing PUs to the planter will work effectively. Experimentation will typically improve efficiency by best utilizing the skills of the personnel involved. However, when SCUBA is required for planting, many logistical and safety problems are introduced (*sensu* Merkel 1992). At the least, higher wages associated with diving significantly increases planting costs sometimes by an order of magnitude.

Merkel (1992) gave careful consideration to the role of personnel and the use of volunteer labor. For intertidal bare-root (e.g., staple technique) planting he suggested a minimum of 7 persons (1 project coordinator and 6 staff); for subtidal bare-root planting he suggested a minimum of 9 persons (1 coordinator, 4 staff on shore, and 4 divers). Slightly fewer people were recommended for plug planting. As for volunteers, he points out that after the relatively brief learning curve for executing seagrass plantings, they often lose interest as the work is tedious and repetitive. Paid staff are often more cost-effective.

Plug Methods

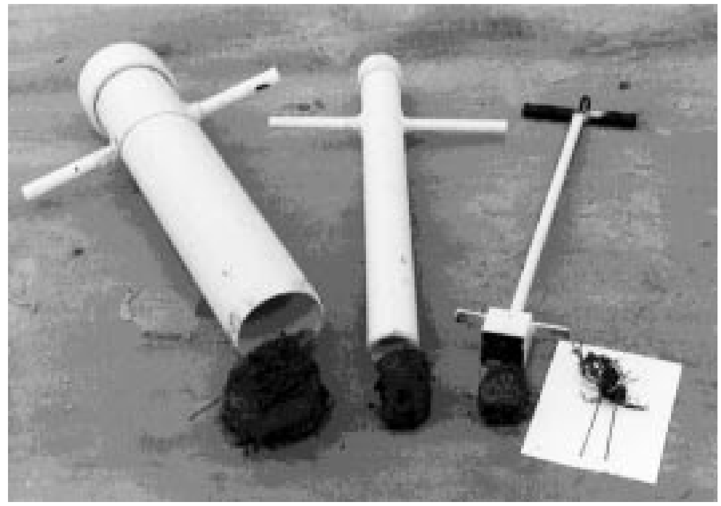


Figure 3.1. Comparison from left to right of 6" diameter plug or core, 3" diameter core, 9" square peat pot plug and staple unit. Note differences in size of collection apparatus and mass of material to be handled among techniques; this is a large part of the basis for differences in logistic burdens among techniques.

Plugs of seagrass with the associated sediment can be harvested using a core tube. Core tubes (Figure 3.1) are used to extract plugs from the donor bed and transport them in the tube to the planting site. The tube (usually 4-6 inch diameter PVC) is inserted into the sediment and capped, creating a vacuum so that when the tube is pulled from the sediment the small plug of seagrass with associated sediment is carried inside. Another cap is placed over the bottom to avoid losing the plug in transport. Another hole must be made at the planting site to accommodate the plug. This can be accomplished either by removing another core or by softening the bottom using a wedge. Fonseca (1994) described using tree planting bars of the kind employed in forestry practices for this purpose. To plant the plug, the bottom cap is removed from the core tube, and then the core tube is inserted into the new hole. The top cap is then removed, letting the plug slide out of the tube into the substrate. This method requires handling the caps and core tubes between planting and the next harvesting. Because of this handling time, the core tube planting was the most expensive (3.53 work-minutes per planting unit) tested by Fonseca et al. (1994). Costs for all methods included only work time to harvest, fabricate planting units, and plant those units. No transportation time, lodging, capital expenditure for equipment, boats, overhead or profit was included. Basic cost may then be computed by multiplying the number of planting units (PU) needed by time per PU and then by hourly wage. However, this method has been used extensively and for most species with good results.

Use of plugs requires that the sediment-root mass be sufficiently cohesive so that it remains in the tube when the plug is pulled from the bottom. The ability to retain a plug in the core tube varies inversely with particle size and core diameter, but positively with depth of the plug (filling more of the core tube with sediment; unfortunately with concomitant increase in mass) or root mat thickness.

Staple Method

The staple method has been used widely since its development in the late 1970's (Derrenbacker and Lewis 1982, Fonseca et al. 1982). Plants are dug up using shovels, the sediment is shaken from the roots and rhizomes in the process, and the plants with the roots and rhizomes are placed in flowing seawater tanks (or floating pens) for holding until made into PUs. Surprisingly, this handling results in no measurable loss in photosynthetic efficiency by at least some seagrass (*Zostera marina*), even after repeated insertion into the sediment. Groups of plants are attached to staples by inserting the root-rhizome portion of the group under the bridge of the staple and securing the plants with a paper-coated metal twist-tie (Figure 3.2). The twist tie is secured around the plants at the basal meristem so that the leaves will extend from under the staple up into the water column when planted. A small strip of paper has been used to protect the rhizomes from the twist-tie by wrapping the group of plants with the paper and securing the twist-tie over the paper strip. The staples are then inserted into the sediment so that the roots and rhizomes are buried nearly parallel to the sediment surface, as they occur in nature. (Fonseca et al. 1982, 1984). Loosening the sediment with a utensil such as a dive knife facilitates placing the roots into the sediment. One person may lay out the planting units beforehand at the appropriate spacing, while a second person follows and installs them.

This planting method takes less time than the core tubes, but the intermediary step of attaching plants to staples is time-consuming (see below). In calm areas, groups of plants may be stapled to the bottom without attaching them to the staples beforehand. When attached to the staples, these plantings have successfully withstood tidal velocities of up to ~50 cm/sec (Fonseca et al. 1985). The staple method required 1.91-2.07 work minutes per PU in a test by Fonseca et al. (1994). The relatively low cost and widely tested applicability make this one of the most useful methods available at this time.

Some criticism has been leveled at the use of metal staples, because the bridge of the staples will oxidize before the legs which are deeper in the typically anaerobic sediment, leaving two potentially sharp pieces of metal in the bottom (Merkel 1988b). However, we have deployed thousands of these PUs and, despite repeated visits to the sites, have not yet experienced an injury. The use of metal staples described here is emphasized for its sediment-free approach, reducing the burden of carrying associated sediment. Any degradable anchor may be substituted if shown to provide similar stabilization of the plantings until they root. Two variations of this method are described below.

Merkel (1988a) utilized a popsicle-stick technique where shoots were tethered on a short cotton string to a popsicle stick and inserted into the sediment (Figure 3.3). The stick would then rotate to a horizontal position deep in the sediment and resist dislodgement. The bundle of shoots, attached on their lead to the stick would then be resistant to erosion. Although we have not tested this technique, Merkel has used it extensively (pers. com.). It would seem that a fine sediment would facilitate deployment and lead holes as with peat pots or regular staples would be sufficient to install the PU. Also as with any PU, the depth of insertion of the anchor requires attention so as not to allow the plants to float out of the bottom or be held too deep in the sediment, covering the leaves. Information on fabrication and deployment costs are not available for comparison with other methods.

Another variation on the staple method is the use of a biodegradable anchor. Davis and Short (1997) have used bamboo "shish kabob" sticks in place of metal anchors (Figure 3.4). The sticks are soaked to enhance their flexibility and bent in half. The fibrous nature of the bamboo usually prevents complete breakage, thereby forming an inverted "V" or U-shaped staple, much like the prefabricated metal staples. Costs are expected to follow that developed for metal staples although when purchased in bulk, skewers can cost as little as \$0.006 apiece as compared with \$0.01 apiece for metal staples. These sticks lack the weight of a metal staple but are easily moved about if placed on the bottom (i.e., just prior to planting by a diver, pers. obs.) and alleviate concerns regarding potential injury from corroded metal staples. Also, Davis and Short (1997) did not attach plants to the staples beforehand: plants were pinned to the bottom by the diver who carried both staples and plants. They claim a substantial cost saving using this approach.

Peat Pot Method

Fonseca et al. (1994) recently modified the method of Robilliard and Porter (1976a). Peat pot plantings have been found to have the lowest cost per planting unit (1.21-1.49 work minutes per PU), despite the fact that substantial amounts of sediment are moved with the plants (Fonseca 1994). As with the coring method, shearing of blades may impair growth of larger plants. Shoalgrass and potentially widgeon grass and paddle grass (or any *Halophila* species) may be most suitable for this method, given their relatively high density and generally shorter blade lengths than manatee grass. The peat pots used by Fonseca et al. (1994) were 3 inches on a side and are readily available. The 3 x 3-inch sod plugger (Figure 3.5 a-g) used in that study can usually be purchased locally. The sod plugger is used to cut plugs from existing beds. The plug should then be extruded immediately into a peat pot and placed in a hold-

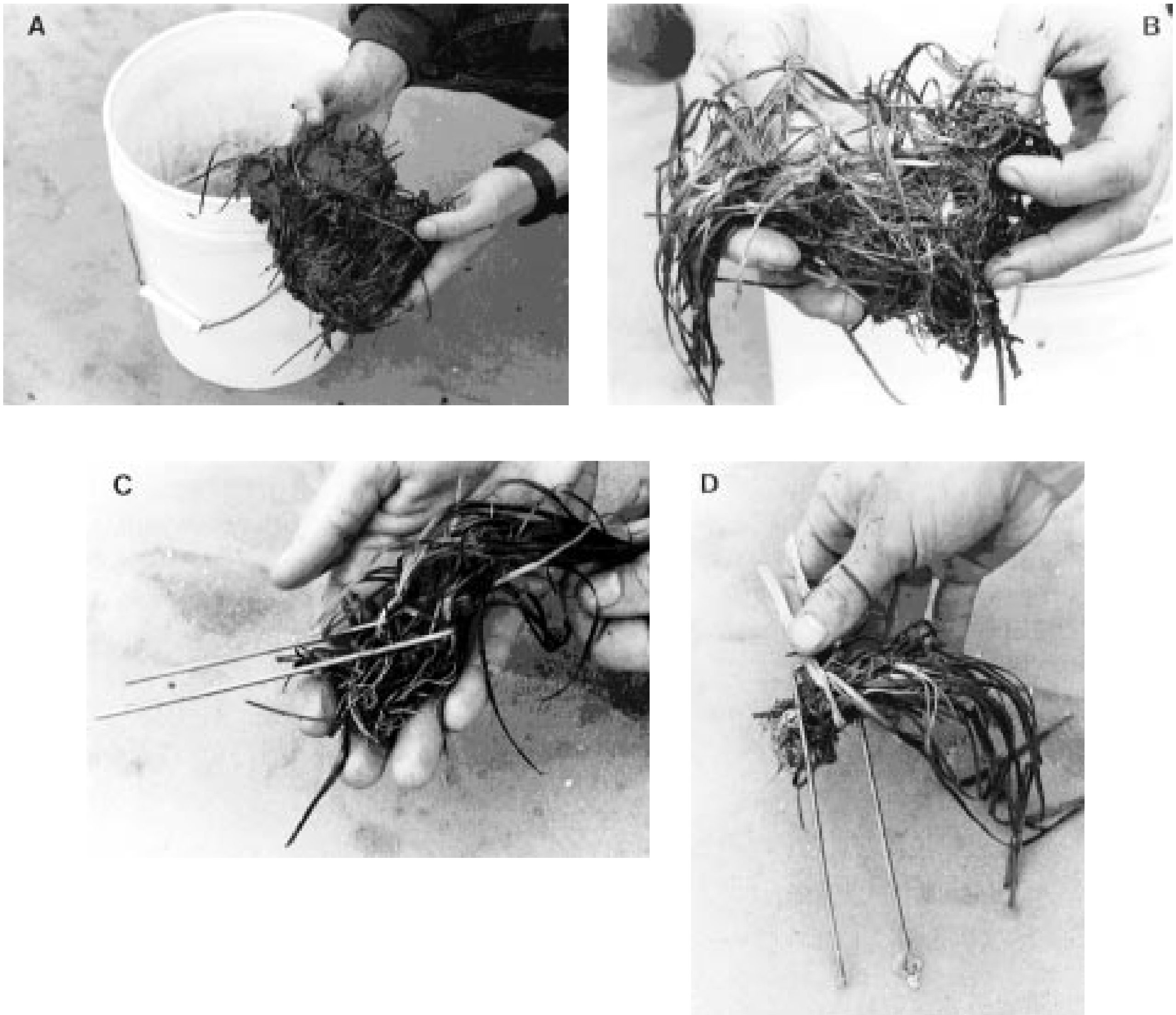


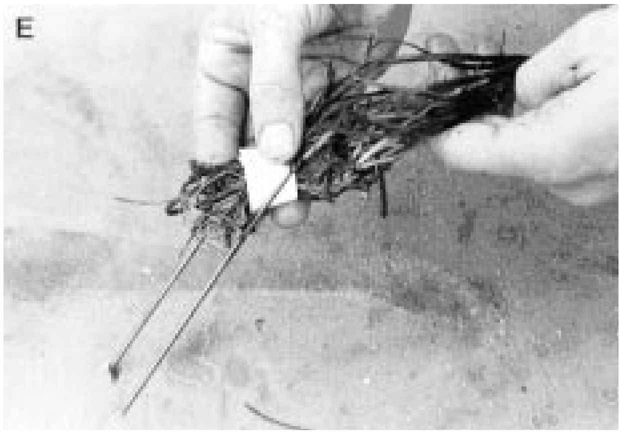
Figure 3.2. Staple Method. (All photographs staged on land and in air for demonstration purposes only; eelgrass Zostera marina *used in this demonstration.)*

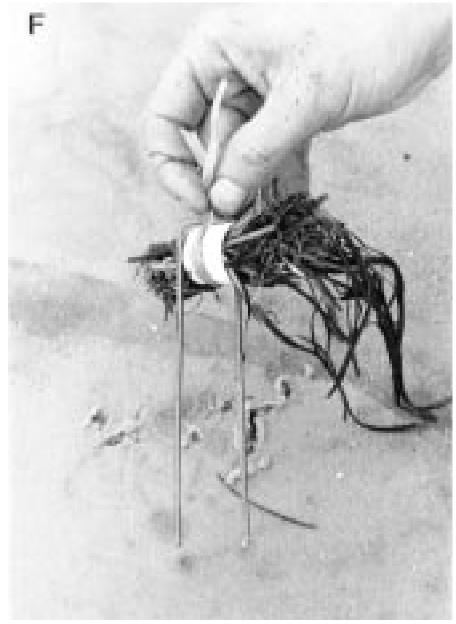
(a) Typical shovel-sized sod that is excavated for collection of planting stock.

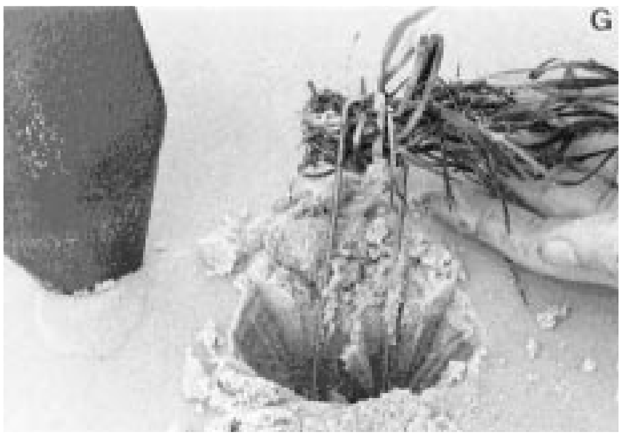
(b) Seagrass shoots remaining after rinsing sediment from sod.

(c) Depending on size of shoots from one (very large, ~1m long plants) to fifteen (small, ~10-20 cm long plants) are separated from the sod. A staple is then placed over the plants where the leafy shoots are attached to the rhizomes, separating what will become the above and below ground portions of the planting unit.

Note: In quiescent settings it may not be necessary to attach shoots to the staples; plants can be separated from sods and stapled into the bottom all in one act. Practitioners of this method work either in pairs where one person separates out planting stock and hands it to and second person who manipulates the staples and inserts the planting unit into the bottom or else planters work alone and develop ways to secure and carry staples. For example, Velcro™ straps have been fabricated to be placed along the forearm of a wetsuit under which many staples can be secured yet easily slid out from under the strap as planting progresses. If a planting does not require pre-planting attachment to staples, then skip the next three steps.







(d) (Opposite page) A paper-coated (not plastic) wire twist-tie™ is then placed under the shoot bundle and over the bridge of the staple and twisted snugly. Care must be taken not to crush the rhizomes and/or shoots when tightening the twist tie. The planting unit is then ready for transport to the planting site.

(e) An optional tactic that is sometimes useful with larger plants whose rhizomes are more brittle is the addition of a paper collar around the shoots prior to the addition of the twist-tie.

(f) The twist-tie may then be attached. The planting unit is then ready for transport to the planting site.

(g) A softened (fluidized) spot is usually created in the sediment unless the sediment is already soft. Because the staple unit is small, this can be accomplished with a dive knife although tree bars work very well. The points of the staple are inserted into the bottom, sometimes at an angle, instead of perpendicular to the sediment surface.

h) The staple is inserted into the sediment to the point where the bridge of the staple is just covered, burying the rhizomes taking care to make sure the plant bundle remains under the bridge of the staple. Also leaves must not be caught under the staple and should be free to extend up into the water column.

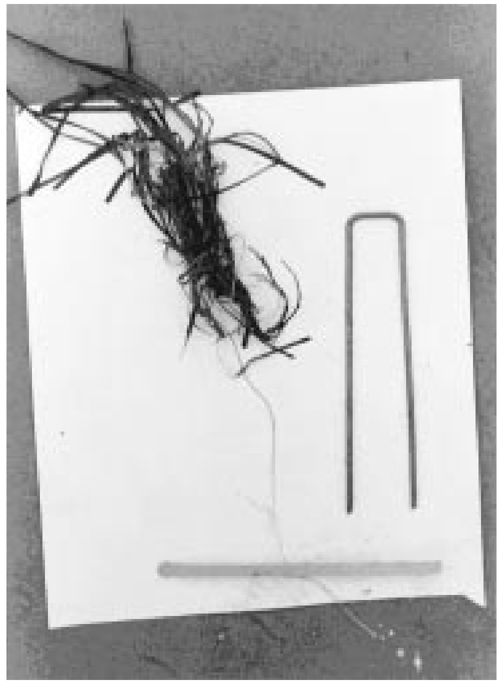


Figure 3.3. A technique developed by K. Merkel (Merkel & Associates, San Diego, CA) as an alternative to staples.. Bundles of seagrass are tethered to wooden anchors (e.g., popsicle sticks or tongue depressors), and inserted into the sediment. The stick remains horizontal in the sediment and holds the seagrass in place until rooting occurs.

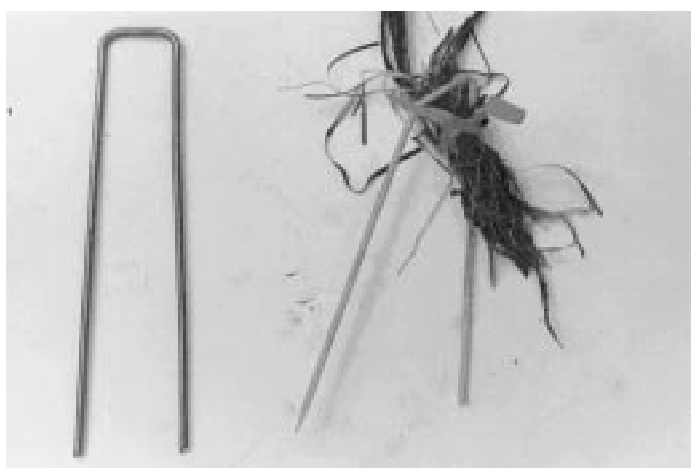


Figure 3.4. A technique developed by R. Davis and F. Short 1997 which substitutes bamboo barbecue skewers (right) for the metal staple (left). The skewers may be soaked overnight to increase their flexibility, and then broken in half. The fibers of the bamboo prevent the two ends of the skewer from separating, forming an inverted V-shaped staple which is used just as the metal staple. Advantage: biodegradable without formation of sharp points as sometimes occurs with metal staples when the bridge portion (nearer the oxygenated sediment surface) rusts away. Disadvantage: sometimes not negatively buoyant and pre-placement of planting units is not always possible.

ing tray. Typically, one person cuts plugs while a second person holds out the peat pots and arranges them in a floating tray. As the trays fill up, they may be sunk to the bottom until moved to the planting site. With either method of handling, all air must be squeezed out of the peat pots prior to submergence or the pots will capsize in the tray. The tray can be stabilized easily by placing a layer of wet burlap over the plants with an aluminum grid laid on top for ballast. The trays should be of a size to facilitate handling (~30 pots per tray). Planting can be accomplished in a number of ways. As with most of these methods, the PUs may be laid out by one person while others follow to plant them. One person loosens the sediment with a tree planting bar while the other person installs the peat pot in the bottom. Once in the bottom, the sides of the peat pot should be ripped down to allow rhizome spread. The rhizomes will not penetrate the peat pot wall. Despite their low cost, use of peat pots must be evaluated over a wide range of conditions before this technique is universally recommended. One such evaluation was provided by a worker in the mid-Atlantic region. Adapted from: "Utilization of Peat Pots in Transplanting Eelgrass" Ben Anderson (Delaware Department of Natural Resources and Environmental Control):

"This describes the methodology being used for the past two years in a program of eelgrass (*Zostera marina*) restoration in the Inland Bays of Delaware. From an operational perspective staple planting would work, but a major draw back was that it was extremely labor intensive. Various methods were tried to reduce the time and expense of the original three day process. The most successful and the method preferred to date was a variation on the above process. Three inch peat pots were used to transport and transplant the eelgrass. This method eliminated a whole day in the process, the most labor and personnel intensive-that of sorting bundling and anchoring the eelgrass planting units. This new process also shortened the time period that the plants were out of their environment and thus eliminated a level of stress that in all probability enhanced the success of the transplant and the well-being of the plants.

"The plants were harvested from the donor beds as before with a long-handled round nosed garden spade. The shovel passed through the sediments just beneath the eelgrass root zone, approximately three inches for these beds. The spade was then lifted to the water's surface and the eelgrass, with its intact sediment load, was transferred to a floating mesh box which was used as a sorting platform.The eelgrass/sediment matrix was gently broken apart into units that contained between 15 and 20 eelgrass shoots. The sediment volume for this size unit was too large to fit into the 3 inch peat pot; the rhizome sediment volume was reduced by gently cradling the roots and sediment in one's hands with fingers slightly spread and lightly massaging the sediment mass while allowing the sediment to fall between the fingers until the

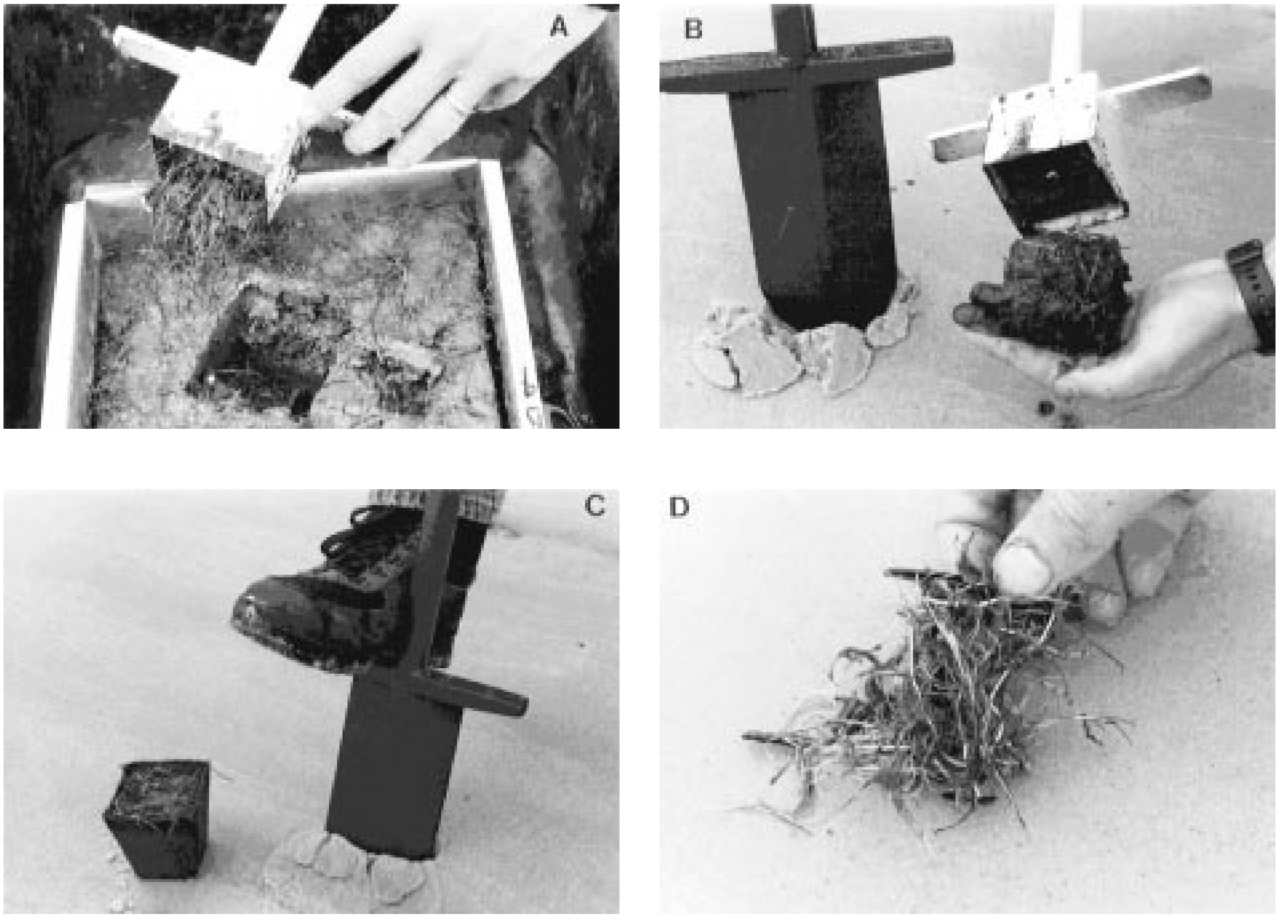


Figure 3.5. Peat Pot. (All photographs staged on land and in air for demonstration purposes only; Halodule wrightii *used in this demonstration.)*

(a) A sod plugger is used to take 3 x 3 inch plugs from existing seagrass beds.

(b) Sod extruded to show size; note extruder plate inside plugger has been depressed to eject the plug. On left is a tree planting bar that is used to soften the sediment (by mixing the sediment with the overlying water; fluidizing) to insert the peat pot.

(c) Tree planting bar softening sediment. When underwater, a hole does not form but a fluidized zone forms in the sand, allowing the peat pot to be inserted easily into the sediment. Taking extra time to form a large fluidized area greatly facilitates peat pot installation. Use of the bar should just precede the installation of the peat pot else the sediment may de-fluidize and harden, preventing installation.

*(d) Peat pot planting material after washing away sediment; note small amount of planting material (*Halodule wrightii *in this case) used in a peat pot unit.*

(e) (Opposite page) Installing peat pot in the sediment.

(f) (Opposite page) A critical step after the peat pot is installed in the sediment: the peat pot walls must be torn down to allow the rhizomes to spread. Seagrass rhizomes often do not penetrate peat pot walls. This should be done immediately after inserting the peat pot into the bottom while the sediment is still fluidized.

(g) Summary of peat pot planting process. From right to left; a peat pot with fertilizer pellets prior to receiving a sod; sod cutter with extruder plate down; peat pot with sod, and installed peat pot with near wall torn down.

volume of the root/sediment mass would fit into the peat pot. This sediment reduction was best done in the water with hands just below surface. This allows a substantial degree of control in shaping and "feeling" the loss of the sediments until the dimension of the sediment/root volume approximates that of the peat pot. It was also important to overfill the peat pot so that a dome was created with sediment and roots in order to allow the rhizomes to creep over the peat pot as they grow and not allow a point of attachment for algae growth on the peat pot which would thus compete with the eelgrass. The potted eelgrass units are then placed into 9.5 gallon stackable Rubbermaid™ plastic storage trays approximately 24 x 16 x 8 inches for transport. Approximately 45 to 55 potted eelgrass units fit each tray. Our experience has shown that about 700 potted units can be collected by a three person team in about three hours. The team consists of one person on the shovel gathering the plants and two persons sorting and packing the peat pots.

"The trays were kept out of direct sunlight until planting and may be placed submersed in a shallow protected cove for a few days without any noticeable harm done to the plants. The trays have sufficient weight from the contained sediments to remain submerged and can be further stabilized by stakes and rope should conditions dictate. After a planting grid was placed on the planting site, peat pots were planted by divers, using a small hand garden shovel, at each intersect node in the grid matrix. The peat pot was totally buried in the sediments with the "dome" of the eelgrass and sediments flush with the existing sediment surface. Any portion of a peat pot exposed to the water will invite colonization of algae and thus may compete with the eelgrass for resources. When inserting the peat pot into the sediment it may be advantageous to "crack" the peat pot sides gently and lightly before planting the pot into the hole. This will allow the newly formed roots an easy path into the sediments and allow for faster root colonization in its new location. The planting grid was carefully removed, being careful not to disturb or damage the transplants."

Other Methods

A wide variety of methods are reviewed by Phillips (1982), Fonseca et al. (1988), and Harrison (1990). These include the use of whole sods, plastic pots, iron rods, concrete rings, wire mesh, plastic bags, attachment to construction re-bar, nails, and seeds. But of all non-whole plant methods, the use of seedlings is currently receiving widespread attention yet has had little actual application. Sowing seeds of seagrass has been studied for a temperate species (R. Orth, Virginia Institute of Marine Science, Gloucester Point, VA, pers. com.) and large areas (acres) have been established in the Chesapeake Bay by this approach. Granger et al. (1996) has experimented with pelletization of seeds as well as embedding seeds in biodegradable mesh; these experiments are in progress at this time and appear promising. Seeding techniques currently hold what we consider the highest promise for large-scale restoration of some damaged seagrass species. However, seed predation and stabilization (hydrodynamic regime) are two important issues to consider in use of seeds. Areas of high seed predation or high currents/waves may be problematic in application of this seed technique, although Granger et al.'s (1996) pelletization method may help overcome these problems. With *Zostera*, seed collection must be performed months in advance of a planned project. Given the lead time required for many planting projects, though, this should not be an impediment. However, this approach is now feasible for only one (*Z. marina*) and perhaps two other species (*R. maritima* and *T. testudinum*). Thorhaug (1974) introduced *Thalassia* seedling planting, and Fonseca et al. (1985) and others have all used *Thalassia* seedlings and a patented turtle grass seedling grow-out method has been registered by Lewis (1987). These methods appear to work, but are ultimately dependent on wild stock harvest of seeds and may be better suited for quiescent areas.

Meinesz et al. (1992) have successfully used plastic meshes with attached shoots, similar to the employment of degradable erosion control fabric by Fonseca et al. (1979). However because of their plastic components, both methods are now illegal in this country. Further, Fonseca et al.'s mesh was actually not bio- but photo-degradable; a feature that was severely compromised in the estuarine sediment. Others have attempted planting of freshwater and brackish water species using biodegradable mesh bags containing PUs dropped overboard (Durako et al. 1993). There has been mixed success and these methods have only been tested in small-scale experiments. Stout and Heck (1991) found no survival of bagged *Vallisneria* tubers while staple units had ~75 percent survival. Coconut fiber erosion control mats have been tested with micropropagated *Ruppia maritima* (5 planting units per 20x20 cm mat; M. Durako, University of North Carolina at Wilmington, Wilmington, NC, pers com.). Planting units were pinned to the mat with hair pins and mats attached to the bottom with erosion-control staples (see Staple Method, above). One advantage to this method is that shoots are held erect and are less susceptible to burial.

Another technique using manila line or twine has been mentioned to us independently by K. Merkel (Merkel and Associates, San Diego, CA) and the late K. Bird (Univ. North Carolina, Wilmington, NC), working on the West and East Coasts, respectively. The line method simply involves untwisting the line (or twine) itself which is a 3-ply, using a very loose lay, and inserting shoots between the open lays of the line (Figure 3.6). The line has enough resilience to close again, holding the shoot in place. Coils of line with inserted plants can then be quickly fabricated and payed out on a planting site and stapled to the bottom. Planting times are not available but this could be a very promising technique, especially in quiescent areas. It may be prudent to cut the line periodically so that after it is installed an errant propeller does not wrap up large portions of the planting area.

Figure 3.6. Line planting technique (suggested by several contributors). Seagrass shoots are inserted through natural fiber string, such as baling twine and pinned to the bottom (shown here with metal staples). String can be coiled in water-filled tubs and paid out over the side of a boat or floating tubs allowing rapid installation. We suggest that periodic cuts be made in the line after installation so that any failures (such as propeller entanglement) are not transmitted to large numbers of plants.

Another planting method has been developed by (F. Short, Univ. New Hampshire, pers. com.) that, like the cotton mesh bag method of Durako et al. (1993), is designed to avoid the cost of divers. The TERFS (transplanting eelgrass remotely with frame systems; Figure 3.7) may overcome several other potential planting problems. One is that this technique is suitable for deployment in contaminated areas (e.g., PCBs) that might otherwise not affect plant growth but would make diving operations extremely costly, not to mention hazardous. Thus, this method may be

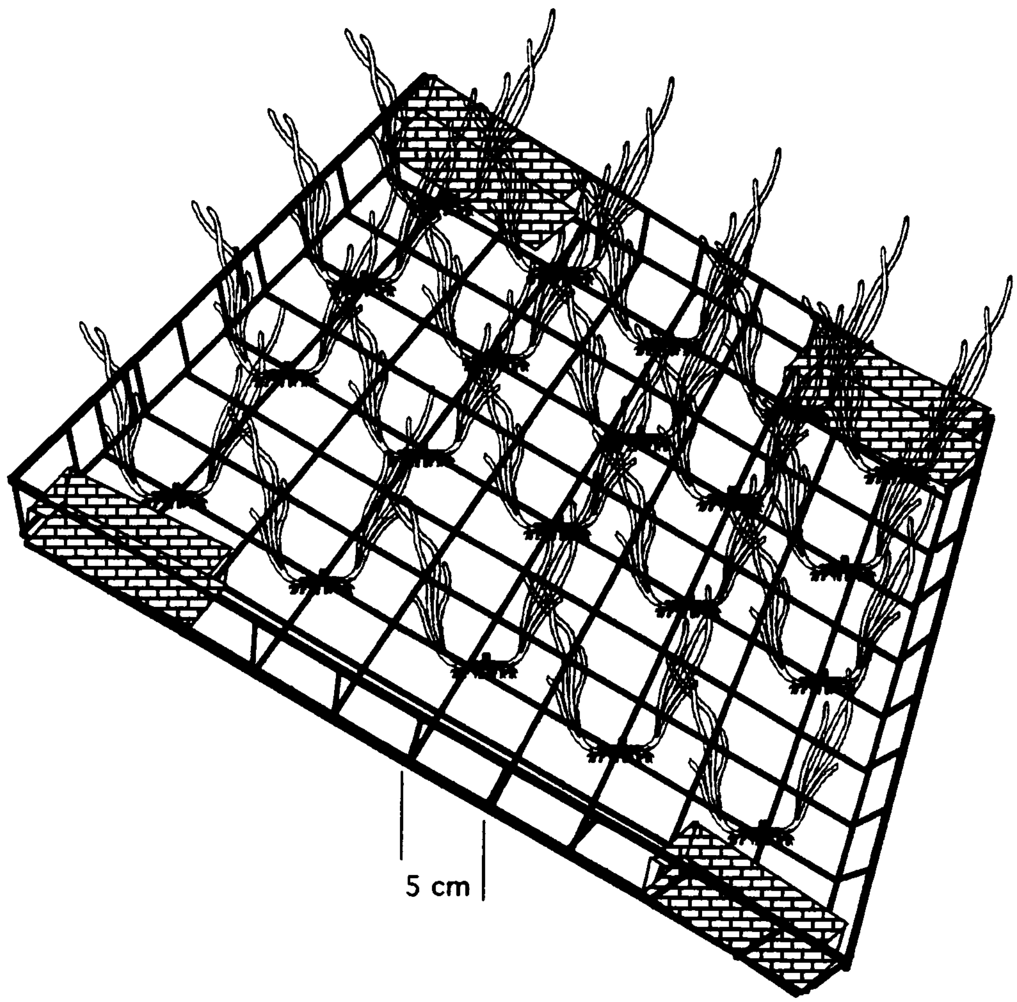


Figure 3.7. Remote planting method (TERFS: Transplanting Eelgrass Remotely with Frame Systems, developed by F. Short, Univ. New Hampshire), designed to avoid the cost of divers and for deployment in contaminated areas (e.g., PCBs) that might otherwise not affect plant growth but cause diving operations to be costly and hazardous. This method may also be applied as a bioassay tool. Plants are attached to the frame with paper ties, the frame can be retrieved after a suitable rooting time, leaving the plants in the sediment.

applied as a bioassay tool. The frame also may minimize some bioturbation hazards. Because the plants are attached to the frame with paper ties, the frame can be retrieved after a suitable rooting time, leaving the plants in the sediment. Strict cost comparisons are not yet available, but these remote techniques are promising for specialized applications.

For hydrodynamically rigorous settings, plantings with large sods may be appropriate. This approach is only now being applied (E. Paling, Murdoch Univ., Perth, Western Australia, pers. com.). Massive sods with their intact rhizospheres may possess sufficient integrity to allow establishment in areas where small cores or bare-root plantings are quickly eroded or exposed during sediment migration. Care would have to be taken to fully install sods into the sediment. A sod extending into the water column would be highly vulnerable to tidal current-induced erosion or acceleration reaction and lift forces under waves. Costs associated with moving large sods are unknown, but may prove cost-effective as compared with other methods.

FERTILIZER EFFECTS

A potential advantage to the peat pot method over staples is that slow release fertilizer may be added to the pots and installed with the plantings at little additional handling cost (Figure 3.5 g). An innovative technique is needed to add fertilizer to the sediment with other planting methods (see section on "Nutrient Requirements for Transplanting," above, to aid in guiding choices on application). J. Anderson (Ruskin, FL, pers. com.) has developed a pontoon boat system for injecting plant hormones and liquid fertilizer into the margins of prop scars but no data are currently available to assess its effectiveness. Previous work by Orth (1977), Pulich (1985), Fonseca et al. (1987b), Williams (1990), and Kenworthy and Fonseca (1992) has met with mixed results, due at least in part to suspicious performance of the fertilizer. Fonseca et al. (1994) did find slow-release pellets to be empty after the prescribed 70-day release period, with all their fertilizer apparently solubilized. They observed a significant increase in shoalgrass population growth in sediments which contain approximately 1.2 percent carbonate but only in association with phosphorus addition. Additions of nitrogen alone or in combination with phosphorus had little or no apparent effect. However, when these experiments were repeated, only nitrogen additions had any significant effect. These results are similar to those found by Short et al. (1985) and Powell et al. (1989) who found phosphorus-linked stimulation of seagrass productivity in carbonate sediments. Fonseca et al. (1994) and Kenworthy and Fonseca (1992) recommend that peat pot plantings of *H. wrightii* in sediments containing > 1.0 percent carbonate may benefit substantially from initial additions of slow-release phosphorus fertilizer. The recent findings of Duarte et al. (1995) suggest that iron limitation in carbonate sediments may also be significant, implying the need for iron additions to plantings in carbonate sediments.

Spacing of Planting Units

Quiescent Settings

Much attention has been given to row spacing of plantings (Fonseca et al. 1982, 1984, 1985, 1987b,c, Merkel 1988b). The reader is directed to those references for a detailed study of the derivation of appropriate spacing. In practice, PU spacing typically ranges from 0.5 to 2.0 m on center. More rapid coalescence of bottom coverage is logically achieved with higher planting density. The benefit of increased rate of coalescence is offset by substantially higher costs due to the number of PUs involved. For example, a 100 m X 100 m (1 hectare) planting area planted on 2.0, 1.0, or 0.5 m centers would require 2,500, 10,000, or 40,000 PUs, respectively.

Wave-Exposed or High Current Speed Settings

In areas with currents over 30 cm/sec, or with long fetches (over 1 km), one may anticipate that the seagrass beds do not naturally cover the bottom completely (Patriquin 1975, Fonseca et al. 1983) (Figures 1.3,1.6, 2.4). In these instances, planting at high densities such as 0.5 m centers, in groups of plantings 5 to 10 m on a side will probably improve the chance of survival. Experimentation is needed for planting in high energy settings. As a result we offered a generalized planting modification scheme (Figure 2.5). Because percent cover by seagrass decreases nearly linearly with both wave exposure and current speed, we devised a decision matrix for calculating row spacing and grouping of plantings based on these models (Figure 3.8). These models are based on seagrass beds (mixed *H. wrightii* and *Z. marina*) in North Carolina (Figure 2.4); we have evidence to suggest that these models will not predict seagrass coverage as well in areas that do not have strong tidal currents. We are confident, however, that the general approach of modifying the arrangement of PUs to accelerate bed form development toward expected patchy, rather than continuous cover is appropriate. We urge users to modify this approach as might seem appropriate given the wide range of conditions that constitute high-energy settings.

1) Compare % cover estimate from equations on p. 75

2) Use smaller % cover value of those found using those equations

3) Compute required area of seafloor to be planted:

Impacted are (1M) * (1/% cover) = mitigation area
Ex: 1M = 5,000 m^2 Predicted % cover = 30%

note: 1M is based not only on area directly impacted but additional acreage computed for interim loss

5,000 * (1/0.3) = 16.667 m^2 of seafloor must be planted in this wave and/or current climate to achieve the total 1M acreage

4) Compute a nominal planting unit (PU) density (this is not the total number for the project)

Based on nominal 1 m spacing of PU under quiescent conditions...

$\boxed{\sqrt{1M} = x \quad \text{then,} \quad (x + 1)^2 = \text{Nominal PU density: save for later computations}}$

$\sqrt{5,000} = 71. \quad (71 + 1)^2 = 5.184$ PU

Make observations of local patch sizes:
Ex: local patch sizes appear to be -10 x 10 m

5) Take the total area of seafloor to be planted (here 16,667 m^2) and divide it into subunits of the local patch size and multiply by predicted percent cover e.g., 30% cover:

(16,667 / 100) * 0.30 = 50 subunits (where 50 * 100 = original 5,000 m^2 to plant)

6) Take the square root of that area:

$\sqrt{5.000} = 71$

7) Divide by the square root of the number of PU:

$\sqrt{16,667} = 130$ which is: 71 / 130 = 0.55 m spacing

8) Multiply the reciprocal of spacing * square root of patch area, square that value and then multiply by the number of subunits to compute TOTAL NUMBER OF PU FOR THE PROJECT

$((1 / 0.55) * \sqrt{100})^2 * 50 = 16,529$ PU (note the correspondence between this number and the actual area of seafloor to be planted)

Figure 3.8. Computing row spacing with strong effects of waves and/or tidal currents.